■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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Of Interest to Managers

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In addition to the regular summary of Delta Water Project Operations by Kate Le, this issue's Quarterly Highlights includes articles on delta smelt culture and conservation activities by Theresa Rettinghouse, Joan Lindberg, and Bradd-Baskerville-Bridges. A continuing decline in delta smelt has led to fewer broodstock, which may be needed to found refuge populations of this imperiled species. Lindberg and Baskerville-Bridges describe initial plans for genetic work that will be used to help maintain diversity of captive populations.

April Hennessy's Quarterly Highlight describes a change in the taxonomy for a mysid shrimp, one of the most common prey species in the estuary. Accurate taxonomy is critical to tracking trends in organisms in the estuary, and is particularly helpful in the detection of alien species.

The last Quarterly Highlight is from Rachel Lux, who reports spring 2007 trends in fish catch by the USFWS Delta Juvenile Fish Monitoring Program. This is typically the time period when most wild salmon, tagged salmon, and other native fishes are captured.

The core of the Summer 2007 IEP Newsletter is a series of articles about the hydrology of the San Francisco estuary during Water Year 2005. Each section was written by a University of California student as part of a course taught by USGS scientist David Schoelhamer. These articles represent a commendable effort by Schoelhamer to provide "real-world" experience for university students, and to provide IEP with useful data summaries.

Finally, the Summer 2007 issue of the IEP Newsletter contains another impressive list of recent scientific papers on the San Francisco estuary and its tributaries. The list includes 123 articles published in scientific journals and another 7 in books. Approximately 20 percent of these articles included IEP staff as authors, were funded in part by IEP, or relied heavily on IEP data or samples. This large number of publications reflects the strong commitment by IEP and others to producing scientifically rigorous information about the region and its biota.

IEP QUARTERLY HIGHLIGHTS

DELTA WATER PROJECT OPERATIONS

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During April through June 2007, both the Sacramento River and San Joaquin River flows were very low due to a dry spring with minimal precipitation as shown in Figure 1. Sacramento flows ranged between 200 cms and 500 cms. San Joaquin flows ranged between 50 cms and 100 cms. NDOI flow patterns were similar to that of Sacramento River with considerable fluctuation as shown in Figure 1. NDOI flows ranged between 180 cms and 500 cms. The mid-June increase in Sacramento River flow was in response to releases to meet X2 outflow objective.

April through June 2007 export actions at SWP and CVP were operated to X2 standard and VAMP, and constrained by delta smelt concerns. Pumping in April and May was for X2 objective and VAMP. VAMP ended late this year at the end of May, rather than mid-May, at the request of the fisheries agencies due to a high level of concern for delta smelt take level at the SWP and ongoing presence of smelt in south Delta. As a result, pumping at both water projects was curtailed into the second week of June as shown in Figure 2. In early June, SWP had minimal pumping at Banks to meet health and safety levels in the aqueduct with no water intake at the Clifton Court gates for nine days. By mid-June, CVP was allowed to increase pumping at the normal rate. SWP restrictions continued due to concern for the level of smelts take at SWP.

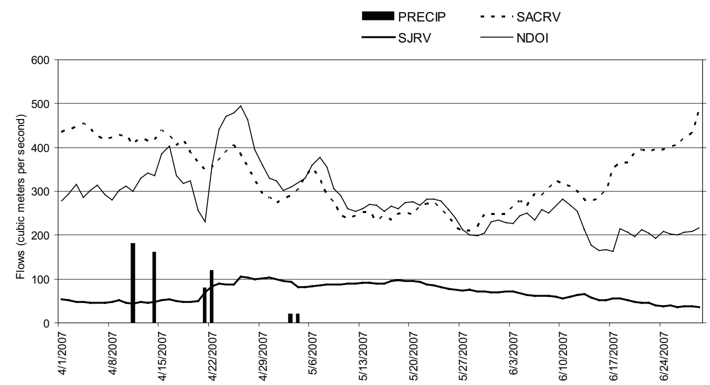

Figure 1 April through June 2007 Sacramento River, San Joaquin River, Net Delta Outflow Index, and Precipitation

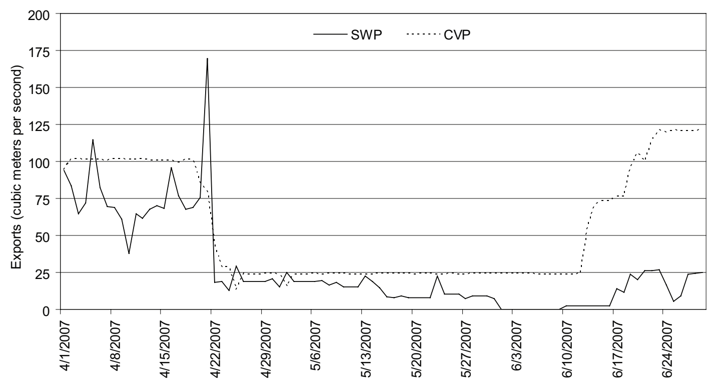

Figure 2 April through June 2007 State Water Project and Central Valley Project Pumpings

Fish Conservation and Culture Lab (FCCL) Update

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The FCCL has provided all life stages of cultured delta smelt fish over the last several years to state and federal agencies for research. A summary of fish provides in 2006 is shownd below. (Table 1) We are currently contracted through IEP to provide 15,000 juvenile delta smelt and 7,500 adults for each of the next 3 years (July 2007 – June 2010) to Pelagic Organism Decline Research (POD) and the U.S. Bureau of Reclamation (USBR) for fish screening efficiency.

Table 1 Total number of each life stage of delta smelt provided January - December 2006

Project	*Agency - Investigator*	*Larvae <20mm*	*Juveniles 20-50mm*	*Adults >50mm*	*Total*
Skinner Fish Facility: CHTR Studies	CDFG - Fujimura, Morinaka, Afentoulis, Aasen		2339	3787	6126
Delta water & toxicity testing	UCD - Werner	3090	2165	4	5259
Wild fish condition and aging	UCD- Bennett			12	12
Predation on natural zooplankton	SFSU- Kimmerer/Sullivan	150			150
Fish pathology check for LSNFH	USFWS - Pathology Lab-Foott		65		65
Refugia development-backup population	LSNFH - Rueth			1039	1039
Fish screen efficiency	USBR - TFCF	5966	3000	3048	12014
Fish identification	USBR - Wang			60	60
*Surplus****	USBR,UCD	25229	10675		35904
Subtotals		34435	18244	7950	
Total fish supplied in 2006					**60629**

***Acronymns**: CDFG: California Department of Fish & Game; CHTR: Capture,Handling,Transportation & Release;UCD: University of California, Davis; SFSU:San Francisco State University;USFWS: US Fish and Wildlife Service;LSNFH: Livingston Stone National Fish Hatchery;USBR: US Bureau of Reclamation; TFCF: Tracy fish collection facility*

****Surplus larvae and juvenile fish were given to agencies after allocating delta smelt for specified projects,and tank space was limiting at the FCCL.*

Delta Smelt Production for Research and Initiation of a Refugial Population

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The marked decline in delta smelt abundance over the last 5 years and the recent restriction of “take” for 2007 from the wild necessitates a procedural change. The Fish Conservation and Culture Lab (FCCL) plans to hold-over the wild (captive) 1-year-old fish we have on-site to serve as 2-year-old broodstock in 2008. This plan maximizes use of the wild (captive) population and allows production of F_1 generation fish for research to the various agencies and universities in 2008. If the “no-take” allocation persists in 2008, we will spawn cultured F_1 generation smelt to produce F_2’s for research purposes. Should take-restrictions lessen, we will plan to collect, as allocated, to provide a broader genetic base to the parent population.

Currently we are developing plans to create a delta smelt refugial population in collaboration with others at University of California – Davis (UCD) and with the US Fish and Wildlife Service (FWS) using the wild 2-year-old broodstock in 2008. In the first year, 2008, the wild (captive) population of 1000+ fish will serve as the parent population. In subsequent years, it is hoped that we can increase the genetic diversity of the refugial population.

This parental population was obtained from the lower Sacramento River, in fall of 2006, at a time when the smelt are typically concentrated prior to spawning migration. It is unknown whether the genetic diversity of this captive population represents that of the wild population. Comparisons can be made between fresh and preserved fish from various field locations and the current captive population. Future adjustments could then be made to obtain a representative captive population.

Species' genetic diversity will inform the number of family groups required to create a sustainable closed population. Success of this refugial population will require genetic identification of individuals to parental cross, and family groups. DNA microsatellite primers for delta smelt are being developed by Dr. Bernie May of UCD in collaboration with Dr. Bill Ardren of the FWS. Creation of a refugial population(s) will allow continued supply of a genetically diverse population of cultured fish for research and provide some measure of protection for the species, should it be lost in the wild.

Acanthomysis bowmani now *Hyperacanthomysis longirostris*

April Hennessy (DFG, Bay-Delta Region), ahennessy@dfg.ca.gov

Acanthomysis bowmani, the most abundant mysid in the Sacramento-San Joaquin Estuary since its introduction from East Asia in 1993, is now included in the new mysid genus *Hyperacanthomysis* in the new combination *H. longirostris* (Fukuoka & Murano 2000). *A. bowmani* was first described from the lower Sacramento and San Joaquin rivers as a new species by Modlin and Orsi (1997), after first being detected by the IEP Zooplankton Study in summer 1993. The new Light and Smith Manual (2007) recognizes this change and lists *A. bowmani* as *H. longirostris*. Consider referencing this mysid as *H. longirostris* (formerly *A. bowmani*) to alleviate confusion by local readers.

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Delta Juvenile Fish Monitoring Program

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The Delta Juvenile Fish Monitoring Program (DJFMP) of the US Fish and Wildlife Service (USFWS), Stockton Office, has monitored the relative abundance and distribution of juvenile Chinook salmon (*Onchorynchus tshawyscha*) in the lower Sacramento and San Joaquin rivers and in the Delta for the Interagency Ecological Program since the 1970s (USFWS, 2006). The program expanded in the early 1990s to monitor other juvenile fish species.

Trawling

For the reporting period (04/01/07 through 06/30/07), Kodiak trawling was conducted at Mossdale (San Joaquin River RM 54) and midwater trawling was conducted at Sherwood Harbor (Sacramento River RM 55) and Chipps Island (Suisun Bay RM 18). Typically, trawls were conducted 3 days per week, with expanded trawling at Chipps Island (7 days per week) conducted between 04/16/07 and 05/27/07, and 24 hour trawling conducted at Sherwood Harbor (04/16/07-04/17/07, 04/30/07-05/01/07, 05/14/07-05/15/07). Expanded trawling at Chipps Island was due to increased effort to recover tagged Chinook salmon smolts released in Sacramento and was used to calculate through-delta survival. The 24-hour sampling at Sherwood Harbor in Sacramento was used to develop an estimate of midwater trawl efficiency at Sherwood Harbor in Sacramento. Decreased sampling (two days per week) occurred at Sherwood Harbor (05/21/07-06/15/07) due to historical trends. Sampling at Chipps Island was halted after 05/29/07 for the remainder of the reporting period due to concern over bycatch of endangered Delta smelt.

At all 3 trawl sites, unmarked Chinook salmon comprised the majority of the catch. A total of 8,769 unmarked salmon were captured during the reporting period. A total of 3,239 unmarked Chinook salmon were caught at Chipps Island, 3,392 at Mossdale and 2,138 at Sherwood Harbor. Of the unmarked Chinook salmon caught at Chipps, 2,452 were fall-run sized, 779 were spring-run sized and 8 were winter-run sized. The unmarked Chinook salmon caught at Mossdale were comprised of 2,528 fall-run sized, 843 spring-run sized and 21 winter-run sized. Sherwood Harbor saw 1,999 fall-run sized, 1 late fall-run sized and 138 spring-run sized salmon. The late-fall run sized salmon at Sherwood Harbor was caught on 04/17/07 and the last winter-run sized salmon at Chipps and Mossdale were caught on 04/30/07 and 04/26/07, respectively.

During the reporting period, the DJFMP, aided by CA Department of Fish and Game (CADFG), conducted 732 trawls at Mossdale, 324 at Sherwood Harbor, and 441 at Chipps Island. Weekly and total catch per unit effort (CPUE; in fish/10,000 m^3) of all fish species and salmon races were calculated. We captured 14,099 fish from 35 species while trawling: 5,420 fish at Chipps Island, 3,174 fish at Sherwood Harbor, and 5,505 fish at Mossdale. At Chipps Island, American shad (*Alosa sapidissima*; n = 909 fish; total CPUE = 0.96 fish/10,000 m^3) and Pacific herring *(Clupea harengus*; n = 315 fish; total CPUE = 0.33 fish/10,000 m^3) were the most prevalent after unmarked salmon (Table 1). The CPUE of American shad declined in May, while the CPUE of Pacific herring increased, and the other common species were more consistent. At Mossdale (sampling conducted by CADFG), inland silversides (*Menidia beryllina*; n = 658; total CPUE = 1.04 fish/10,000 m^3) were the most abundant after salmon, followed by threadfin shad (*Dorosoma petenense;* n = 326 fish; total CPUE = 0.51 fish/10,000 m^3) (Table 2). The CPUE of both silversides and threadfin increased in June, as did the other common species. At Sherwood Harbor, all species other than unmarked salmon were caught in very low numbers. Rainbow trout (*Oncorhynchus mykiss*) had the highest occurrence during the sampling period (n = 7 fish) with a total CPUE = 0.04 fish/10,000 m^3).

A total of 1,244 marked (adipose fin-clipped) Chinook salmon were recovered during the sampling period; 368 at Chipps Island and 876 at Sherwood Harbor. No fin-clipped salmon were recovered at Mossdale during the sampling period.

Beach seine

For the reporting period (04/01/07 through 06/30/07), the DJFMP collected a total of 448 beach seine samples at 52 sites (see USFWS, 2006 for site map). We conducted 76 seines on the lower Sacramento River (7 sites), 59 seines on the San Joaquin River (7 sites), 265 seines in the Delta (29 sites), and 48 seines within San Pablo and San Francisco Bays (9 sites). Lower Sacramento, Delta, and San Joaquin sites were typically sampled once per week, and Bay sites were sampled every other week.

A total of 22,854 fish from 52 species were captured in beach seines during the sample period: 7,238 fish from the lower Sacramento River, 11,285 fish from the Delta, 2,828 fish from the San Joaquin River, and 1,503 fish from the Bay region.

Sacramento suckers (*Catostomus occidentalis*) were the most prevalent species in the lower Sacramento River catch (n = 5,285 fish; total CPUE = 2.23 fish/10,000 m^3) followed by Sacramento splittail (*Pogonichthys macrolepidotus*; n = 367 fish; total CPUE = 0.15 fish/10,000 m^3) (Table 3). In the San Joaquin and Delta seines, red shiners (*Cyprinella lutrensis*) were the most abundant catch (n = 1,363 fish; total CPUE = 0.53 fish/10,000 m^3 for San Joaquin; n = 4,782 fish; total CPUE = 0.35 fish/10,000 m^3 for the Delta). Sacramento suckers were the second most abundant catch in the San Joaquin (n = 842 fish; total CPUE = 0.33 fish/10,000 m^3), while silversides (n = 2,464; total CPUE = 0.18 fish/10,000 m^3) were second in the Delta (Table 4). Top smelt (*Antherinops affinis*; n = 818 fish; total CPUE = 0.24 fish/10,000 m^3) and yellowfin goby (*Acanthogobius flavimanus*; n = 164 fish; total CPUE = 0.05 fish/10,000 m^3) were the most abundant fish caught in the Bay seines.

Five marked (adipose fin-clipped) Chinook salmon were recovered in seines during the sampling period: three were recovered in lower Sacramento River seines, and 2 were recovered in the Delta.

A total of 288 unmarked salmon were recovered while seining. Of these, 280 salmon were fall-run sized (119 from lower Sacramento River and 161 from the Delta), 1 was late-fall sized (Delta) and 7 were spring-run sized (Delta). No winter-run sized salmon were seen in the seines during the reporting period. All of the salmon were recovered during April and May, and no salmon were captured during the last month of the reporting period. No salmon were recovered from the San Joaquin River or Bay region seines during the reporting period.

Table 1 Weekly catch per unit effort (CPUE, in fish/10,000 m^3) of the five most abundant fish species between 04/01/07 and 06/30/07 at Chipps Island midwater trawl

Week starting	*Chinook salmon*	*American shad*	*Pacific herring*	*Striped bass*	*Sacramento splittail*
4/1/2007	*0.51*	*2.62*	*0.00*	*0.14*	*0.09*
4/8/2007	*1.51*	*2.30*	*0.02*	*0.36*	*0.03*
4/15/2007	*2.82*	*1.48*	*0.08*	*0.15*	*0.10*
4/22/2007	*9.60*	*1.16*	*0.06*	*0.24*	*0.04*
4/29/2007	*8.42*	*0.65*	*0.08*	*0.08*	*0.04*
5/6/2007	*4.86*	*0.33*	*0.30*	*0.05*	*0.02*
5/13/2007	*0.78*	*0.39*	*0.29*	*0.15*	*0.05*
5/20/2007	*0.52*	*0.42*	*1.53*	*0.08*	*0.02*
5/27/2007	-	-	-	-	-
6/3/2007	-	-	-	-	-
6/10/2007	-	-	-	-	-
6/17/2007	-	-	-	-	-
6/24/2007	-	-	-	-	-
n	*3,848*	*909*	*315*	*135*	*44*
% of catch	*70.99*	*16.77*	*5.80*	*2.50*	*0.81*

Table 2 Weekly catch per unit effort (CPUE, in fish/10,000 m^3) of the five most abundant fish species between 04/01/07 and 06/30/07 at Mossdale Kodiak trawl

Week starting	*Chinook salmon*	*Inland silverside*	*Threadfin shad*	*Striped bass*	*Red shiner*
4/1/2007	1.12	3.02	0.26	0.00	0.26
4/8/2007	4.99	3.83	0.60	0.05	0.70
4/15/2007	6.97	0.87	0.34	0.02	0.07
4/22/2007	16.69	0.48	0.37	0.02	0.11
4/29/2007	5.64	0.20	0.07	0.01	0.12
5/6/2007	8.38	0.42	0.01	0.01	0.14
5/13/2007	4.29	0.05	0.16	0.00	0.05
5/20/2007	6.33	0.04	0.48	0.02	0.12
5/27/2007	4.11	0.00	0.50	0.03	0.30
6/3/2007	-	-	-	-	-
6/10/2007	1.20	0.11	1.09	0.00	0.39
6/17/2007	0.00	3.56	1.93	1.76	0.40
6/24/2007	0.00	7.01	4.50	3.92	0.15
n	3788	658	326	129	127
% of catch	68.81	11.95	5.92	2.34	2.31

Table 3 Weekly catch per unit effort (CPUE, in fish/10,000 m^3) of the five most abundant fish species between 04/01/07 and 06/30/07 in lower Sacramento River beach seines

Week starting	*Sacramento sucker*	*Sacramento splittail*	*Golden shiner*	*Western mosquito*	*Sacramento pikeminnow*
4/1/2007	0.46	0.00	0.01	0.00	0.00
4/8/2007	0.04	0.00	0.01	0.00	0.00
4/15/2007	0.35	0.00	0.00	0.01	0.00
4/22/2007	0.13	0.00	0.00	0.00	0.00
4/29/2007	0.62	0.08	0.10	0.02	0.08
5/6/2007	0.55	0.03	0.00	0.01	0.03
5/13/2007	2.27	0.18	0.11	0.08	0.18
5/20/2007	3.12	0.81	0.19	0.04	0.81
5/27/2007	5.02	0.03	0.01	0.15	0.03
6/3/2007	6.38	0.22	0.66	0.24	0.22
6/10/2007	3.26	0.35	0.11	0.24	0.35
6/17/2007	1.45	0.10	0.26	0.11	0.10
6/24/2007	5.01	0.18	0.45	0.17	0.18
n	5285	367	340	219	201
% of catch	73.02	5.07	4.7	3.03	2.78

Table 4 Weekly catch per unit effort (CPUE, in fish/10,000 m^3) of the five most abundant fish species between 04/01/07 and 06/30/07 in Delta region beach seines

Week starting	*Red shiner*	*Inland silverside*	*Sacramento sucker*	*Golden shiner*	*Sacramento splittail*
4/1/2007	0.08	0.04	0.00	0.00	0.00
4/8/2007	0.74	0.17	0.13	0.00	0.00
4/15/2007	0.17	0.03	0.24	0.00	0.00
4/22/2007	0.76	0.66	0.34	0.00	0.00
4/29/2007	0.36	0.36	0.23	0.00	0.02
5/6/2007	0.11	0.00	0.39	0.00	0.07
5/13/2007	0.09	0.01	0.25	0.00	0.02
5/20/2007	0.01	0.00	0.00	0.05	0.01
5/27/2007	0.70	0.00	0.25	0.05	0.04
6/3/2007	5.11	0.05	0.12	0.02	0.00
6/10/2007	0.34	0.08	0.01	0.13	0.00
6/17/2007	0.72	0.03	0.00	0.02	0.00
6/24/2007	0.05	0.66	0.00	0.07	0.00
n	4782	2464	2233	341	186
% of catch	42.37	21.83	19.79	3.02	1.65

Contributed Papers

Hydrology of San Francisco Bay and Watershed, Water Year 2005

David H. Schoellhamer (dschoell@ucdavis.edu)

Hydrology is the study of the properties and distribution of water. California has two distinct hydrologic seasons: a wet season from late autumn to early spring with the remainder of the year being dry. Thus, the water year, which begins on October 1 and ends on September 30, is a convenient period to study hydrology because it begins in the dry season, includes a single wet season, and ends in the dry season.

The purpose of this series of short articles is to describe the hydrology of San Francisco Bay and its watershed during water year 2005 (WY2005). The articles describe precipitation and surface water flows in the watershed (Figure 1), flows and diversions in the Sacramento – San Joaquin River Delta (Figure 2), and salinity, suspended sediment, temperature, and chlorophyll-*a* in San Francisco Bay (Figure 3). Temporal variation and spatial distribution are described and WY2005 conditions are compared to historical conditions. All data are available to the public from online sources. Due to the breadth of the subject matter and quantity of data available, the articles provide highlights of the hydrology of the Bay, Delta, and watershed during WY2005 rather than in-depth analysis. Water managers and scientists may find that the articles are a convenient resource to access hydrologic conditions in WY2005.

These articles were written and reviewed by the students enrolled in the class *Hydrology of San Francisco Bay and Delta* that I taught at UC Davis in Spring 2006. The students also downloaded and processed the data presented in these articles. I would like to thank the many individuals, organizations, and agencies who serve the public by collecting and disseminating hydrologic data and Jay Davis, Roger Fujii, Neil Ganju, Karyn Heim, Fred Hetzel, John Largier, Lester McKee, Cathy Ruhl, and Doug Thompson for their assistance.

Figure 1 Central Valley watershed that drains to San Francisco Bay with selected rivers, reservoirs, and streamflow gages shown

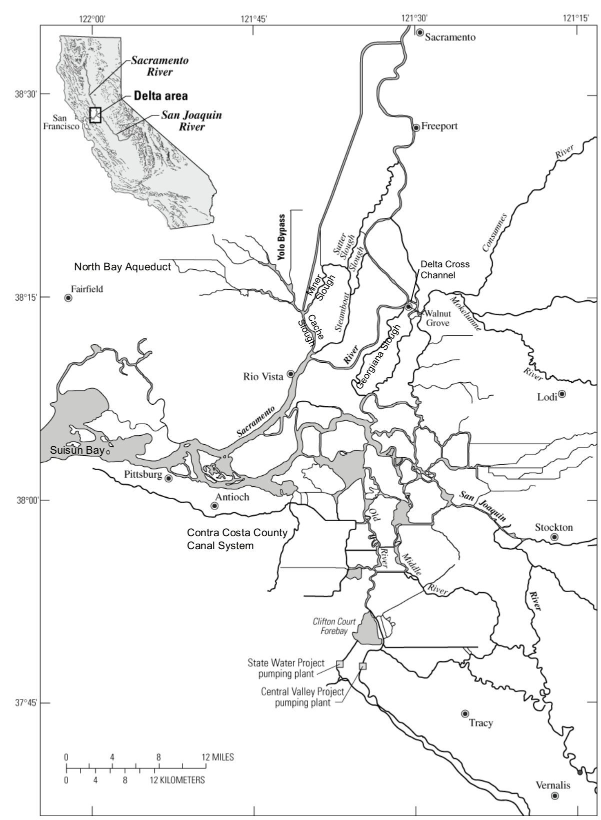

Figure 2 Sacramento-San Joaquin River Delta

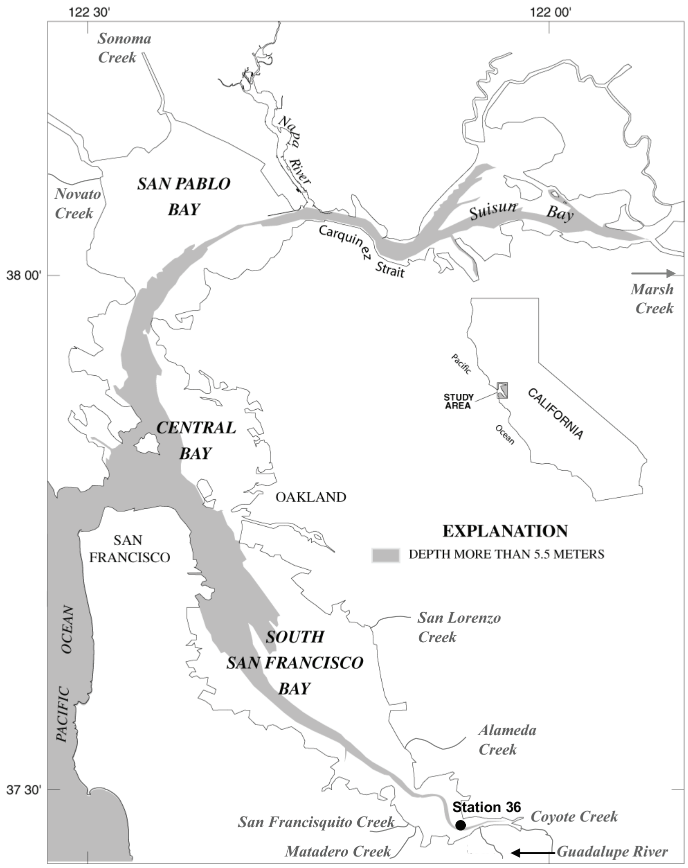

Figure 3 San Francisco Bay

Precipitation in the San Francisco Bay Watershed, Water Year 2005

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Water year (WY) 2005 was wetter than average in both the Sacramento (114% of average, based on 32 stations) and San Joaquin River (135% of average, based on 25 stations) watersheds (CDEC 2006a, Figure 1 in Schoellhamer, this issue). With few exceptions, snowpack was greater than average each month by a consistent margin rather than a consistent percentage. This margin ranged from about 5-10 inches water equivalent (WE) in the Sacramento River basin and approximately 15-20 inches in the San Joaquin River Basin. The greatest levels as well as the greatest margin above average levels were seen in the southern San Joaquin region, which includes the San Joaquin River (50.7 inches WE total snowpack), Tuolumne River (51.7 inches WE total snowpack), and Merced River basins (54.8 inches WE total snowpack). Figure 1 presents snowpack in the American River basin, which illustrates trends typical to the Sacramento and San Joaquin River watershed.

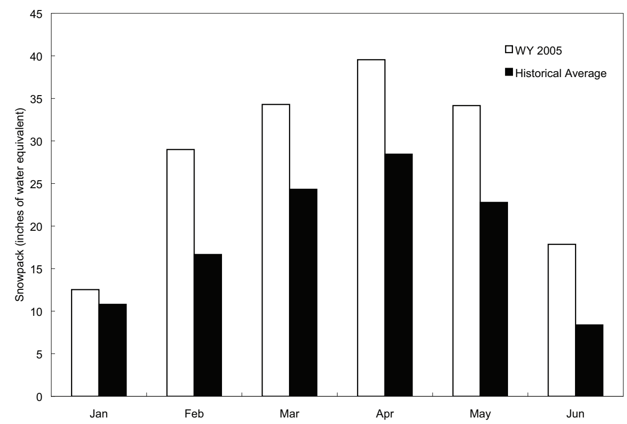

Figure 1 Water year 2005 snowpack (water equivalent) and monthly averages for the period of record in the American River basin (CDEC 2006a)

Figure 2 presents rainfall in the Yuba-Bear and San Joaquin River basins, which illustrate trends typical in the Sacramento and San Joaquin River watersheds, respectively (CDEC 2006b). Rainfall variations generally alternated between wet and dry months in the Sacramento basin, while the San Joaquin River basin experienced wetter than average months throughout winter. As compared to average historical values, in both basins October, May, and June were significantly wetter, March was moderately wetter, and November was significantly drier. In the San Joaquin River Basin, January was significantly wetter, while February was significantly drier in the Sacramento River basin. Notable extremes included the wet beginning (October) and end (May) of the wet season of WY 2005.

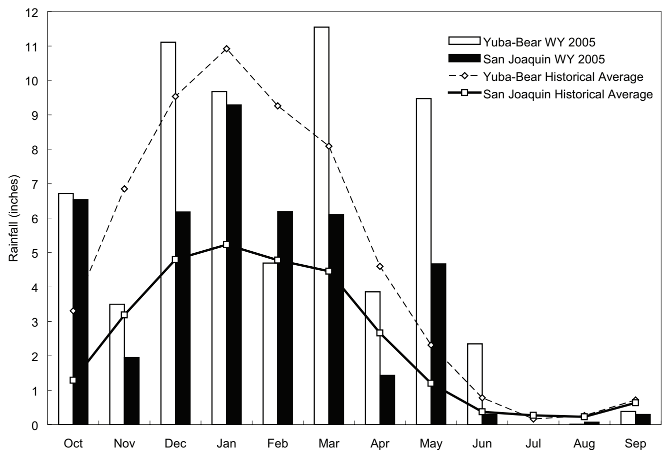

Figure 2 Water year 2005 rainfall and historic monthly averages for the period of record for the Yuba-Bear and San Joaquin River basins (CDEC 2006b)

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Sacramento River Flows, Water Year 2005

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The Sacramento River was characterized by an oscillatory flow pattern in water year 2005 (Figure 1). Periods of high flow were seen in accordance to the precipitation pattern of WY2005, (Figure 1, Giudice, this issue) and an unusually wet spring coupled with a relatively dry fall caused the center of mass of total flow from the Sacramento River basin to shift from its historical average of March 11 to April 9. Flow in the lower section of the river had three distinct flow peaks that correspond to the three largest precipitation periods - late December / early January, late March, and mid-May. Historical high flow marks were recorded during the flow peak of May 22 and 23 at Freeport with flows of 74,100 and 70,800 CFS, respectively. Despite having predominantly lower than average flow for the first seven months of the water year, the flow past Freeport almost reached its total volumetric average by September 30 (Table 1), due largely to an above average snowpack (Figure 1, Giudice, this issue) and wet months of May and June that generated large amounts of runoff (Figure 2, Giudice, this issue). Flow in the river caused overtopping of the main flood control weirs during the three peak flows in January, March and May, inundating the Sutter and Yolo Bypasses. Flow in the Yolo Bypass near Woodland (USGS 11453000) showed similar structure to the flow past Freeport with a spike of nearly 8000 CFS occurring on May 23. Although flow was high throughout the basin, the Sacramento Weir was never opened.

Despite the large size of the watershed, which covers 27,000 square miles, all major tributaries in the basin showed similar flow trends. The three main reservoirs in the watershed, at Shasta, Oroville, and Folsom also displayed similar characteristics, switching from below average to above average storage around April, and approaching their capacities by the late spring. Storage in the reservoir system remained high throughout the summer due to runoff generated from the snowpack and a series of late spring storms (Figures 1,2, Giudice, this issue). The gradual release of this water added to the observed trend in Figure 1 of above average flows in the Sacramento River for May through September.

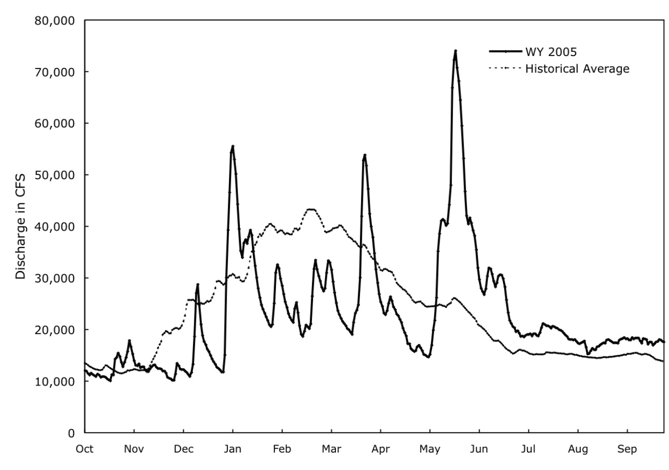

Figure 1 Flow of the Sacramento River at Freeport, California, collected from USGS station (USGS 11447650). Similar trends were observed in all major reaches of Sacramento River tributaries during water year 2005.

Table 1 Comparison WY 2005 and historical flow data for Sacramento River at Freeport collected from USGS station 11447650

	Oct.	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical monthly avg. flow (CFS)	12322	16052	26325	35207	40697	37736	29108	24755	18403	15454	14781	14911
WY 2005 monthly avg. flow (CFS)	12606	12250	17745	33681	24875	30368	22133	40219	28653	19668	17245	17933
Percent of historical	102%	76%	67%	96%	61%	80%	76%	162%	156%	127%	117%	120%
Cumulative percent of avg. yearly flow passing Freeport in WY 2005	4%	9%	15%	27%	35%	46%	54%	68%	78%	85%	91%	98%

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San Joaquin River Flows, Water Year 2005

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Runoff from the above average precipitation over the San Joaquin River basin (Figure 2, Giudice, this issue), contributed to high water levels throughout the basins' major reservoirs (Figure 1, Schoellhamer, this issue). The major reservoirs in the southern San Joaquin region, which include Millerton (Friant dam), Lake McClure and New Don Pedro, reached their capacities in late June or early July. Whereas, the major reservoirs in the northern San Joaquin region, which include New Melones, New Hogan and Camanche, only approached their capacities in late June or early July. The greater water equivalent snow pack experienced in the southern San Joaquin region (Giudice, this issue) may have contributed to the relatively higher water levels in the southern reservoirs. New Don Pedro reservoir (Figure 1) illustrates the general reservoir trends for WY2005 in the San Joaquin River basin. All reservoir storage data was obtained from CDEC (2006).

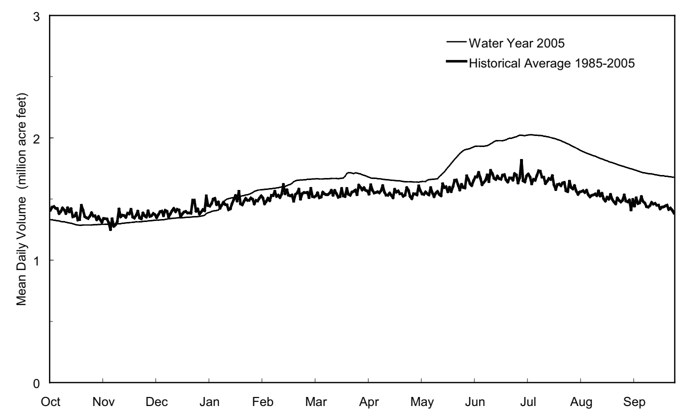

Figure 1 New Don Pedro reservoir WY2005 mean daily reservoir volume and averages for the period of 1985 to 2005

While the major reservoirs throughout the San Joaquin River basin were at or approaching their capacities, the river flows were also noteworthy. For example, the maximum mean daily flow in the San Joaquin River at Vernalis (Figure 2) was approximately 15,300 cfs for WY2005, which is nearly double the historical average of 8,162 cfs. Historically, the volume of the hydrograph was, on average, approximately 3.3 million acre-feet (maf), with its approximate center of mass at March 29. During WY2005, the volume of the hydrograph was approximately 3.8 maf, with the center of mass shifting to April 19. The hydrograph includes outflows from Millerton, Lake McClure, New Don Pedro and New Melones reservoirs, as well as flows from smaller streams. Also worth noting is the operation of the James Bypass, which connects the Kings River basin to the San Joaquin River, and usually only operates during wetter years. During WY2005, the James Bypass conveyed runoff during the end of May and early June, with a maximum mean daily flow of approximately 2,500 cfs. Historically, the James Bypass has little or no flow for all or most of the year and has an average of the maximum mean daily flow, during the years of operation, of approximately 3,121 cfs. Although the bypass flows are typically small compared to the overall system flows, the operation of the bypass itself indicates a wetter than normal year. Flow data for Vernalis and the James Bypass was obtained from USGS (2006) flow monitoring stations 11303500 and 11253500, respectively.

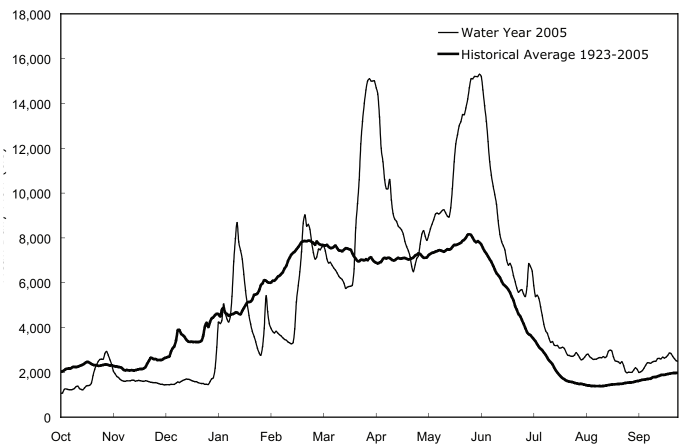

Figure 2 San Joaquin River at Vernalis WY2005 mean daily flow and averages for the period of 1923 to 2005

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Flows in Local Bay Tributaries, Water Year 2005

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Hydrologic conditions of tributaries that drain watersheds directly adjacent to San Francisco Bay (Bay tributaries) were evaluated for water year (WY) 2005 using daily flow data collected by the U.S. Geological Survey (USGS) at ten stations (USGS 2006, Table 1, Figure 3 in Schoellhamer, this issue). Drainage areas upstream of individual gauges ranged from 7.6 square miles for Matadero Creek at Palo Alto (USGS 11166000) to 633 square miles for Alameda Creek near Niles (USGS 11179000) and comprised a total area of approximately 1,530 square miles or approximately 60% of the entire watershed area of the Bay Area. The heavily urbanized local watershed area is less than 4% of the watershed area of the Sacramento and San Joaquin Rivers, which cumulatively provide approximately 90% of the annual freshwater inflow to the Bay (Conomos and others 1985).

The total flow volume measured in Bay tributaries in WY 2005 was approximately 0.55 million acre-feet (maf). This volume was 3.6% of the total flow volume entering the Bay via the Sacramento/San Joaquin River Delta (15.4 maf) in WY 2005, as represented by the Net Delta Outflow Index in the Dayflow computer program (IEP 2006). Average annual flow rates measured in individual tributaries during WY 2005 ranged from 4 cubic feet per second (cfs) in Matadero Creek (7.6 square mile drainage area) to 249 cfs in Napa River (218 square mile drainage area) (Table 1). Greater than 50% of the total measured flow volume emanated from tributaries that drain two of the largest watersheds: Alameda Creek and Napa River. Compared to historical averages, annual average tributary flow rates in WY 2005 ranged from 119 to 154% above normal with an average of 139% above normal.

Table 1 Annual mean discharge in Bay tributaries, WY 2005. Discharge data were collected by USGS (USGS 2006). Annual mean discharge is in cubic feet per second (cfs).

Bay Tributary	*USGS Station ID*	*Period of Record*	*Drainage Area (square miles)*	*Annual Mean Discharge (cfs)*	
				Historic	*WY 2005*
Alameda Creek	11179000	1891-2005	633	126	179
Coyote Creek	11172175	1999-2005	319	43	62
Napa River	11458000	1929-31, 1960-2005	218	204	249
Guadalupe River	11169025	2002-05	160	69	82
Sonoma Creek	11458500	1955-81, 2001-05	58	70	87
San Lorenzo Creek	11181040	1967-2005	45	22	32
Marsh Creek	11337600	2000-05	38	10	15
San Francisquito Creek	11164500	1930-2005	37	21	30
Novato Creek	11459500	1946-2005	18	13	19
Matadero Creek	11166000	1953-2005	7	3	4

Frequent storm events sustained high seasonal flows relative to base flow conditions for periods of weeks to months during three major series of storm events beginning in late-December, mid-February, and mid-March (Figure 1). Tributaries generally had above-average flows during the storms centered on early-December, late-December/early-January, and mid- to late-February; however, below-average flows were observed for approximately one month prior to the mid-February storms. In addition, above-average tributary flows in late storms of early- and mid-May were heavily influenced by flow in the northern region of the Bay Area (*e.g.*, Napa River). In fact, Napa River flow accounted for greater than 30% of the measured Bay tributary flow from May 10 to 15, 2005 and from May 19 to June 2, 2005.

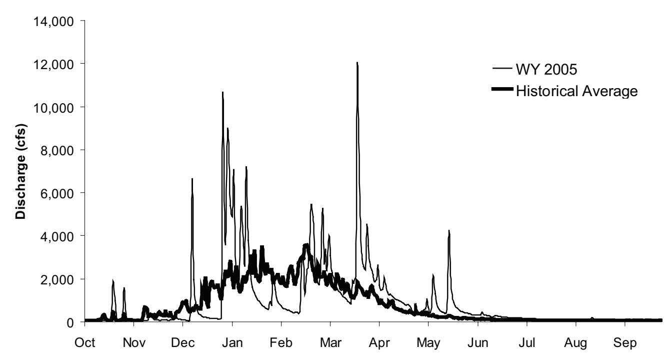

Figure 1 Daily mean discharge in local Bay tributaries in water year 2005 compared to historical averages. Discharge data were collected by USGS (USGS 2006). Daily mean discharge is in cubic feet per second (cfs) and represents the combined flows from ten gauged Bay tributaries listed in Table 1.

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Diversions from the Delta, Water Year 2005

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Daily freshwater diversions from the Delta region in WY 2005 were analyzed using quantities from DAYFLOW, a numerical model developed and maintained by the State of California's Interagency Ecological Program (IEP 2006). DAYFLOW also calculates in-Delta use, which is not reported herein due to the potential error inherent to the calculation. Monitored water removal from four points in the Delta were retrieved, including pumping by the State Water Project (SWP; at the Delta (Banks) Pumping Plant), the Central Valley Project (CVP) (at the Tracy Pumping Plant), the North Bay Aqueduct (NBAQ), and the Contra Costa county canal system (CCC). The sum of these removals is calculated in the program and termed "exports"

The total exports from the Delta during WY 2005 were the highest in the DAYFLOW record (49 years recorded) with an estimated removal of over 6.45 million acre feet of water by these four projects alone. The daily average of total exports was 118% of the average over the preceding decade (Figures 1 and 2). This increase is in line with rainfall, which was 114% and 135% of average during WY 2005 in the Sacramento and San Joaquin River basins, respectively (Giudice, this issue). The SWP diverted the largest portion of Delta water, nearly 54% of the total export, with an average daily mean of 5007 cfs. The CVP withdrew an average 3700 cfs (average daily mean), or 43% of the total export. Other diversions were to the NBAQ and to CCC with average daily mean withdrawals of 66 cfs (<1%) and 164 cfs (2.26%), respectively.

A significant but brief decline in pumping by both SWP and CVP between January 31 and February 9, 2005 resulted in below-average exports in the Delta during this time (Figure 1). At the SWP, this decline was due to pumping only at night to minimize energy costs (Thompson, 2006). Pumping by SWP ceased May 4, 2005, and June 21, 2005, the latter causing a large decline in total diversions June 19 through June 23. These cessations coincided with herbicide treatment in the Clifton Court Forebay (Thompson, 2006). The cessation in May had little effect on the total Delta diversions, which were low for all projects from mid-April through late May to accommodate spring fish runs.

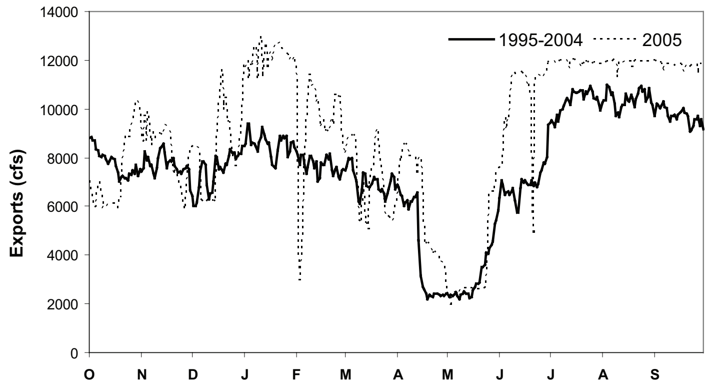

Figure 1 Average Delta freshwater exports (cfs), WY 2005 and preceding decade, 1995-2004. Exports shown from combined CCC, SWP, CVP, and NBAQ Diversions.

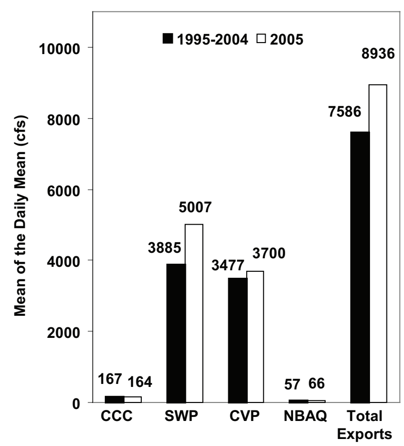

Figure 2 Average daily mean exports (cfs) through NBAQ, CVP, SWP, CCC, and the through the sum of these projects (Total Exports). WY 2005 compared with exports during the preceding decade, 1995-2004.

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Flow in the Sacramento-San Joaquin Delta, Water Year 2005

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This article focuses on water flow in the Sacramento-San Joaquin Delta. Water flow in the Delta is greatly studied because the Delta is a major source of freshwater for California. Flow out of the Delta is dependant on several factors, which consist of tidal flows, and nontidal flows caused by precipitation, river inflows, consumptive use in the Delta, exports to water users, and flooding due to levee breaks. The flow analysis is based on observations of flows on the Sacramento and San Joaquin Rivers at various locations within the Delta region. The reference data for Delta outflow spans from WY 1995 to WY 2004 (IEP 2006, USGS 2006).

Tidal flows vary in direction; landward (flood) and seaward (ebb). Steamboat Slough, Sacramento River at Georgiana Slough, Delta Cross Channel, San Joaquin River at Stockton, and Sacramento River at Rio Vista have seaward tidally-averaged flows, while the tidally-averaged flow at Old River is landward from October to March and June to September and seaward from March to June. The tidally-averaged flow was calculated with a low-pass filter which removed tidal variability from the 15-minute data. During WY 2005, there were three noticeable positive peaks in tidally averaged flows (Jan, Mar, and May) in the upstream areas such as Miner Slough (7396 cubic feet per second (cfs), 7754 cfs, and 11073 cfs), Steamboat Slough (9990 cfs, 9920 cfs, and 14171 cfs), and Sacramento River below Georgiana Slough (21965 cfs, 22252 cfs, and 28607 cfs) (Figure 1). The peaks in tidally-averaged flow correlated with high rainfall (Guidice, this issue) and river flows (Ransom, this issue, and Sanguinetti, this issue).

WY 2005 had an unusually long wet season and the Delta outflow reflected this anomaly (Figure 2). The Delta outflow for WY 2005 was greater than the reference WYs' average outflow for the months of October (144%), May (147%) and June (142%). In the last decade, large peak outflows from the Delta occurred between January and March, except WY 2003, during which a 67663 cfs peak daily outflow occurred on May 8th. However, during WY 2005, the maximum daily outflow of 91492 cfs was on May 22nd. The peak outflows during WY 2005 corresponded to the alternating high inflows in January, March and May mentioned in the Sacramento River article (Ransom, this issue).

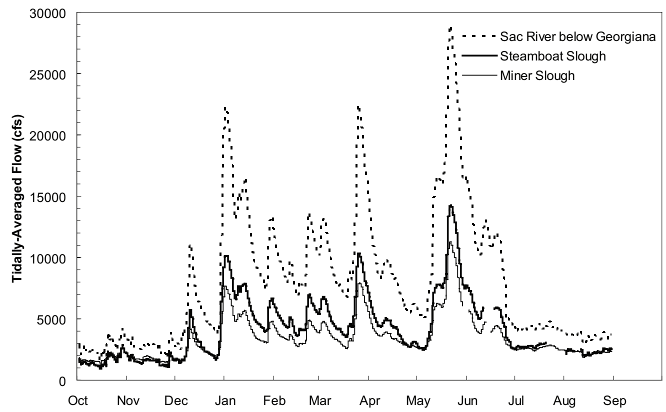

Figure 1 Tidally-Averaged Flow at Sacramento River below Georgiana Slough, Steamboat Slough, and Miner Slough

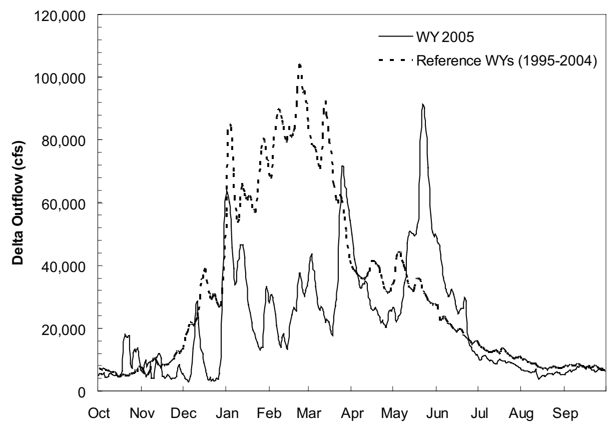

Figure 2 Delta Outflow for the reference WYs (1995 - 2004) and WY 2005

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Salinity in San Francisco Bay and Delta, Water Year 2005

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Salinity data for the San Francisco Bay Estuary (bay) was obtained from the USGS "Water Quality of San Francisco Bay" database (USGS 2006), which collects water quality measurements approximately monthly at 39 fixed sampling locations spaced three to six kilometers apart throughout the bay. The stations are located along the central deep water channel and extend from Station 36 at Calaveras Point, located near the southern tip of the South Bay, to Rio Vista on the Sacramento River.

Because seasonal salinity variations in the bay are highly dependant on freshwater flows from the Sierra Nevada watershed, the salinity data from WY 2005 is inversely correlated to the magnitude of the flow in the Sacramento and San Joaquin Rivers, the two largest rivers in the watershed. These rivers saw their highest flows from April through June of 2005 (Ransom this issue, Sanguinetti this issue), which resulted in below average salinity throughout the bay from April through August of WY 2005. Salinity was above the historical average throughout the bay from November 2004 through March 2005. Figure 1 depicts the deviation of channel bottom salinity with respect to historical averages throughout the bay and delta for the months of September, March, and April of WY 2005. March represents the month with the greatest positive deviation, April represents the month with the greatest negative deviation, and September represents the month that was closest to the historical monthly average. Carquinez Strait was the location with the greatest salinity variability, with salinity varying from + 7.0 to -8.5 psu with respect to the historical average. Salinity was lowest in April 2005 when the 2 practical salinity units (psu) isohaline was at the eastern edge of San Pablo Bay. This was the furthest west the 2 psu isohaline was measured during WY 2005 (USGS 2006).

The South Bay was a well-mixed estuary throughout WY 2005, with surface and bottom salinities varying by less than 1 psu in most instances. The Central Bay appeared to be partially stratified with the bottom salinity ranging between 1 and 3 psu greater than at the surface. Through San Pablo and Suisun Bays, the estuary was more noticeably stratified for much of the year, with bottom salinities 2-5 psu greater than at the surface. These observations are based on periodic monthly data collected in the deep channel of the bay which may neglect localized and episodic stratification.

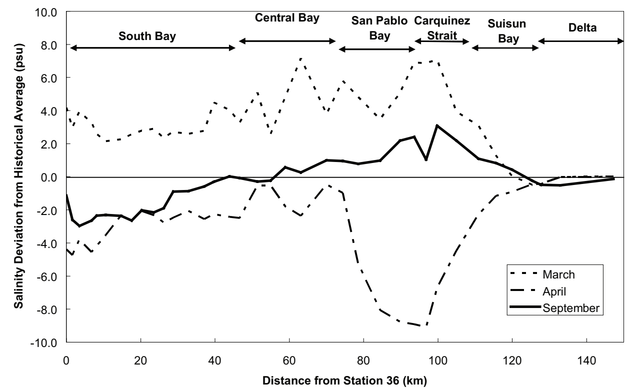

Figure 1 Salinity Deviation from Historical Averages for the Months of March, April, and September of Water Year 2005

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Suspended Sediment in San Francisco Bay and Delta, Water Year 2005

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The USGS has been monitoring suspended sediment concentrations (SSC) since 1968 in the Bay (USGS, 2006). Vertical profiles of SSC data were collected monthly during WY 2005 throughout the estuary as described by Gutierrez (this issue). Many factors, such as freshwater inflows, bay circulation, tidal flows, and winds, induce high temporal and spatial variability of SSC at time scales ranging from hours to a year. However, general variations of SSC during WY 2005 may be described by the data from January, May and August cruises, representing the winter, spring, and summer distributions respectively (Figure 1).

January (Figure 1A) was characterized by high SSC at both landward ends of the Bay with values up to 170 mg/L for bottom suspended sediment (SS) near Coyote Creek and Guadalupe River in South Bay (Schoellhamer, this issue, Figure 3). At the mouth of the Delta, surface and bottom SS also reached their highest concentrations for WY 2005 (70 and 80 mg/L respectively). Elevated Delta outflows in January (Lam Fat Cheong Him, this issue, Figure 2), resulting from the first winter storms, are likely to be the main source of SS in the Bay during this season, as they flush significant amounts of sediment through the watershed. Yet the highest SSC in the northern reach of the Bay were found at Carquinez Strait (110 mg/L) and reflected the existence of an Estuarine Turbidity Maximum (ETM), an expected phenomenon at this location given that the January cruise occurred during spring tide (NOAA, 2006; Schoellhamer, 2001). Although similar SS distributions were observed for the whole winter (December-March), February and March displayed significantly lower SSC than December and January (not shown). Historical minima for February were measured from San Pablo Bay to Suisun Bay for both surface and bottom SSC (8 and 13 mg/L respectively) and were associated with lower than average Delta outflows (Lam Fat Cheong Him, this issue, Figure 2). During this month, upstream dams were not releasing freshwater as they were below average storage (Ransom, this issue; Sanguinetti, this issue), and stratification of the water column was not likely, given that the February cruise took place during a spring tide (NOAA, 2006; Schoellhamer, 2001).

During spring (April-June), high SSC were measured in South and San Pablo Bays and especially in Carquinez Strait (Figure 1B), with historical maxima recorded for bottom SS in San Pablo Bay and Carquinez Strait for each month of this season. Historical maxima in May were as high as 440 mg/L in San Pablo Bay and 767 mg/L in Carquinez Strait. Late elevated freshwater outflow (Lam Fat Cheong Him, this issue, Figure 2) created a large longitudinal salinity gradient in Suisun Bay (Gutierrez, this issue) that produced strong gravitational circulation and an ETM in Carquinez Strait (Schoellhamer, 2001). During summer months (July-September) South Bay was well mixed with low SSC (25 mg/L) in the deep channel, and high SSC could still be found in Suisun Bay and Carquinez Strait (170 mg/L, Figure 1C), while there was no significant freshwater input. Finally, in the fall (September-December) SSC were as low (<20 mg/L) as historical values during this dry season (not shown).

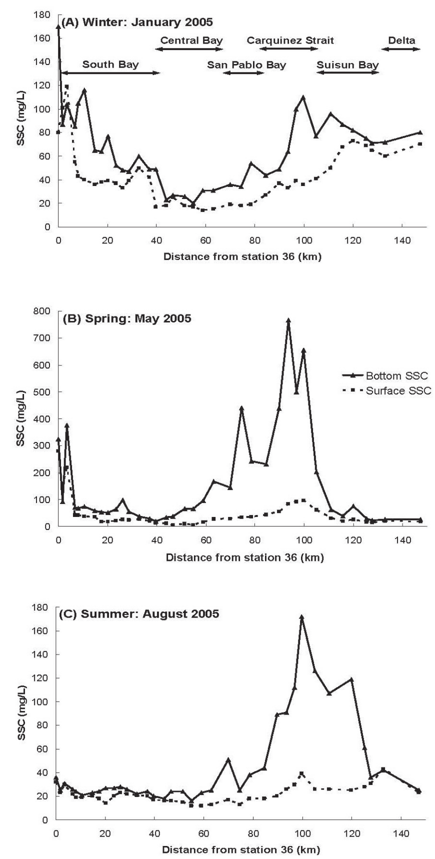

Figure 1 bottom ( ) and surface ( ) suspended sediment concentrations (SSC) collected throughout the San Francisco Bay in January (A), May (B) and August (C) 2005, in mg/L, as a function of the distance of the data point from sampling station 36, located at the southern end of South Bay (Schoelhamer, this issue, Figure 3).

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Water Temperature in San Francisco Bay and Delta, Water Year 2005

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Water temperature is a function of solar radiation, air temperature, cloud cover, wind speed, relative humidity, water depth, and water influx. Thus, San Francisco Bay (SFB) and Delta water temperatures exhibit temporal and spatial variation. This analysis focused on subembayment and seasonal variations using USGS historical and WY 2005 monthly near-bottom temperatures collected along the SFB deep-water channel, and the California Department of Water Resources WY 2005 hourly gage readings within the Delta (USGS 2006, CDEC 2006, Figures 2 and 3 in Schoellhamer, this issue). Maximum depths from USGS data were up to 44 meters, while CDEC depths are typically 1 meter below water surface. Near-surface temperatures exhibited trends similar to the near-bottom temperature trends presented in this article.

Temperatures in SFB subembayments exhibited both inter- and intra-seasonal variation (Table 1). From November to March cooler seasonal air temperatures and precipitation lowered water temperatures, as represented by January data in (Figure 1). Rio Vista on the Sacramento River recorded the lowest temperature at 8.6°C, while South Bay minimum temperatures fell between North Bay and Central Bay minimums (Table 1). April to September temperatures were significantly higher, as represented by September data (Figure 1), with South Bay highest at 23.0°C and followed closely by North Bay landward temperatures. Lower South Bay and the landward end of North Bay had similar WY 2005 temperature ranges, whereas Central Bay had the narrowest range of 6.3°C (Table 1). Seasonal variation in solar radiation, air temperature, and inflow may have been the largest drivers of temperature changes. The narrow inter- and intra-seasonal range in Central Bay may be explained by mixing with ocean water.

It is important to note that hourly CDEC data cannot be directly compared to monthly USGS data; hourly data may appear to have more variability and extremes because it was collected nearly continuously rather than monthly (Table 1). Thus, CDEC hourly data for Rio Vista exhibited a 16.8°C range versus a 12.7°C range from USGS monthly data. The greater degree of variability in the San Joaquin River may be explained in summer by the lower flows of the San Joaquin River (Sanguinetti, M.A., this issue) compared to the Sacramento River (Ransom, O.T., this issue), and in winter by the larger water equivalence in inches of the San Joaquin basin snow pack compared to the Sacramento River basin snow pack (Giudice, B.D., this issue).

When compared to historical data, USGS monthly WY 2005 February (Figure 2) and March (not shown) near-surface and near-bottom temperatures in the North Bay were as much as 1°C higher than historical maximum temperatures for those months. This anomaly is unexplained. All other WY 2005 comparisons to historical temperatures were closer to historical medians.

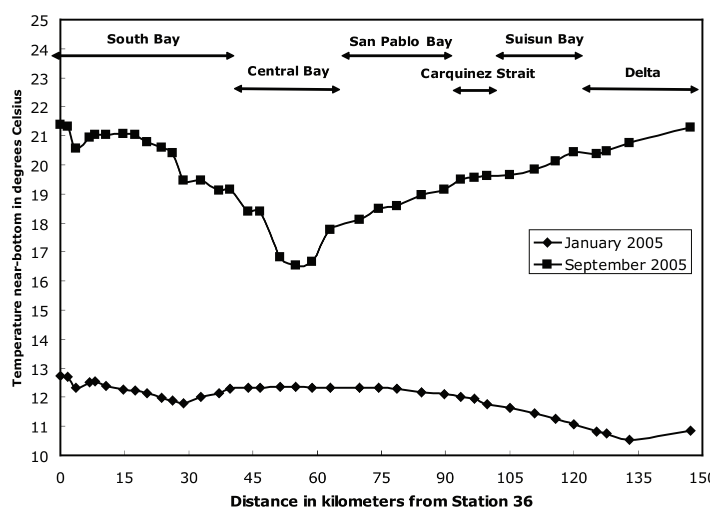

Figure 1 Longitudinal profile of near-bottom temperatures in San Francisco Bay, January and September, WY 2005

Table 1 Temperature minimums, maximums, and ranges in San Francisco Bay and Delta, WY 2005

USGS Stations	*Sample Frequency*	*Minimum Temp (°C)*	*Month*	*Maximum Temp (°C)*	*Month*	*Range (°C)*
South Bay	Monthly	10.4	Jan	23.0	Aug	12.6
Central Bay	Monthly	12.3	Dec	18.6	Aug	6.3
North Bay Carquinez Strait	Monthly	9.9	Jan	20.7	Aug	10.8
North Bay Suisun Bay	Monthly	9.1	Jan	22.0	Aug	12.9
Sacramento River Rio Vista	Monthly	8.6	Nov, Jan	21.3	Sept	12.7
CDEC Stations	***Sample Frequency***	***Minimum Temp (°C)***	***Month***	***Maximum Temp (°C)***	***Month***	***Range (°C)***
San Joaquin River Vernalis Southern Delta	Hourly	7.2	Dec	25.4	Aug	18.2
Sacramento River Rio Vista Northern Delta	Hourly	7.6	Jan	24.4	July	16.8

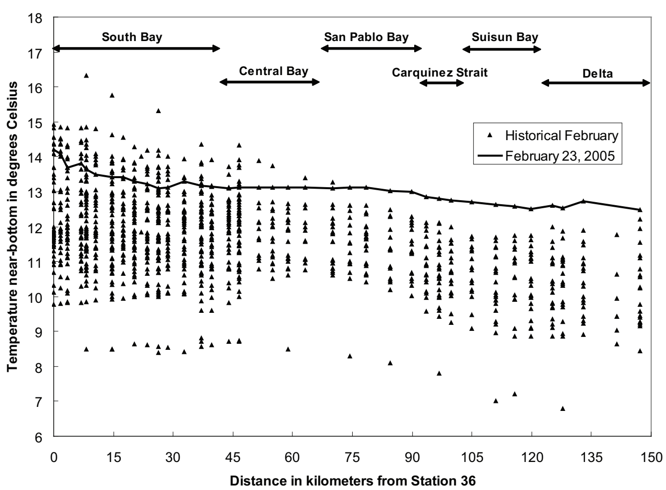

Figure 2 Historical and WY 2005 February water temperature

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Chlorophyll in San Francisco Bay and Delta, Water Year 2005

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Phytoplankton in the San Francisco Bay and Delta have a large impact on nutrient cycling, water quality parameters, and the estuarine food web (Cloern 1996). Chlorophyll, an easily measurable proxy for phytoplankton, varies spatially throughout the bay and temporally on time scales ranging from daily to decadal. Physical factors driving variation in chlorophyll concentrations include tides, freshwater inflows, and meteorological variables such as wind and solar radiation. In particular, the spring-neap tidal cycle is known to have a large effect on chlorophyll concentrations in the SF Bay (Cloern 1996). During spring tides, the available tidal energy is sufficient to vertically mix the water column and expose phytoplankton to a large population of benthic grazers. During neap tides, weaker tidal energy allows vertical density stratification to build, decoupling the photic zone from the benthos and leading to increased phytoplankton growth (Monismith and others 1996). To analyze the spatial and temporal trends in chlorophyll concentrations for

WY2005, surface chlorophyll concentrations were retrieved from the USGS San Francisco Bay water quality database (USGS 2006), which is briefly described by Gutierrez (this issue).

Chlorophyll in WY2005 was noteworthy for the conspicuous lack of a large spring bloom (over 20 mg/m^3) in South Bay. Of the samples taken during the usual spring bloom period (February through May), the highest recorded chlorophyll concentration in South Bay was only 18.9 mg/m^3. This may have been due to sampling events occurring during spring tide (April, May cruises) and increased inflows due to the relatively wet spring experienced by much of the basin (Figure 2, Giudice this issue). However, during this same time period San Pablo Bay concentrations were relatively high when compared to historical averages and the water column was more stratified than elsewhere in the Bay (Figure 1). In addition, the highest monthly chlorophyll concentrations for the period of record were recorded in Suisun Bay in May during a spring tide and when precipitation and inflow were well above average (see previous WY2005 articles).

The largest chlorophyll concentrations of WY2005 were recorded in South Bay during a late summer/early fall phytoplankton bloom (maximum recorded concentration 35.5 mg/m^3). During this bloom, the highest monthly concentrations in South Bay for the period of record were measured for both August and September. The South Bay chlorophyll data was found to be greatly dependent on the tidal cycle, with sampling cruises showing high phytoplankton concentrations in late August and late September (corresponding with neap tides and stratified conditions) and lower concentrations in early August and September (corresponding with spring tides and unstratified conditions) (Figure 2). With the exception of a small phytoplankton bloom in San Pablo Bay in November (maximum concentration 11.3 mg/m^3), the fall and winter data showed chlorophyll concentrations that were approximately average in the remainder of the Bay and Delta.

and September

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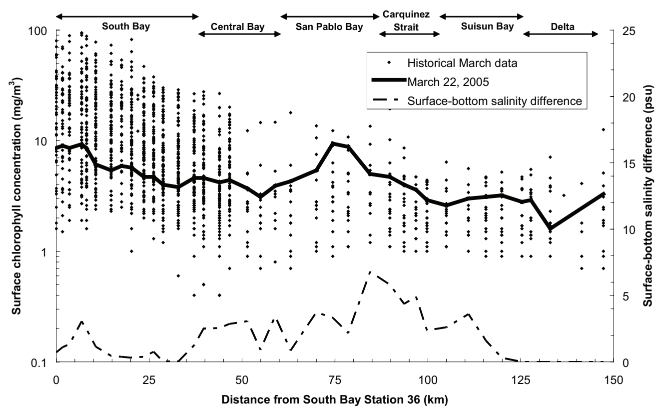

Figure 1 Historical and WY2005 spatial distribution of surface chlorophyll concentrations in the San Francisco Bay-Delta

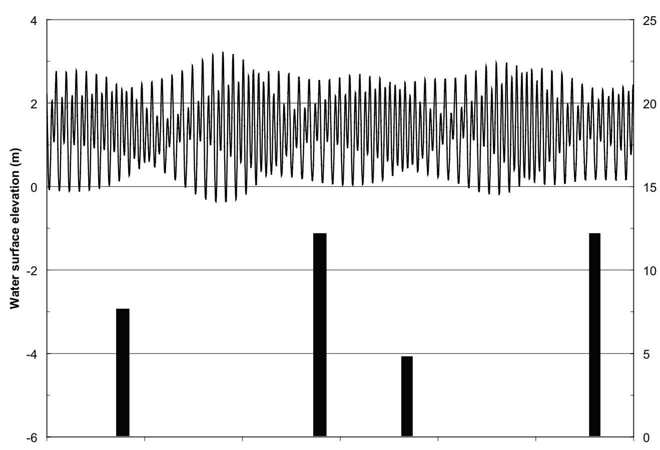

Figure 2 Spatially averaged chlorophyll concentrations for South Bay in August

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